The Dahli Cosmological Model: A Structural Unification of Dark Matter and Dark Energy

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Abstract

We present a structural cosmological model in which dark matter and dark energy are not independent components, but two geometric phases of a single membrane–string substrate. The universe is organized into three domains: (i) P_1, the Einsteinian domain inside galaxies, where General Relativity (GR), Quantum Field Theory (QFT), and the Standard Model (SM) apply as accurate local theories; (ii) P_2, the intergalactic domain, where spacetime is replaced by a network of microscopic white holes composed of stacked mass membranes supported by contracted temporal-energy strings; and (iii) P_3, the halo domain around galaxies, where closed spatial membranes generate the effective gravitational field attributed to dark matter.

A structural order parameter $\alpha(t)$ tracks the fraction of membrane units that have transitioned from a closed, mass-bearing configuration (dark-matter phase in P_3) to an open, vacuum-bearing configuration (cosmic-vacuum phase in P_2). Assuming first-order logistic dynamics for $\alpha(t)$, the effective dark-matter density obeys a modified continuity equation

$$\dot{\rho}_{\mathrm{DM}} + 3H\rho_{\mathrm{DM}} = -\Gamma_{\mathrm{DM}\to\Lambda}, \quad \Gamma_{\mathrm{DM}\to\Lambda} > 0,$$

so that dark matter is structurally depleted and converted into cosmic vacuum. The effective dark-energy density is generated by the tension of contracted temporal strings, obtained via hierarchical damping from the Planck tension to cosmological scales. Thus the cosmological constant is reinterpreted as the large-scale manifestation of cosmic temporal tension, not as vacuum energy of QFT fields.

We provide a logical critique of the standard ΛCDM paradigm by identifying category errors in extending local QFT concepts to the intergalactic domain. We derive quantitative predictions: (1) an extra, distance- and energy-dependent attenuation of high-energy gamma-rays crossing P_2, with a characteristic redshift dependence that encodes dark-matter depletion; and (2) sub-percent corrections to the Casimir force at sub-micrometer separations, controlled by the structural length scale of the membrane–string network. These signatures render the model falsifiable and define a concrete research program that confines GR+QFT+SM to their legitimate local domain P_1, while introducing a new mechanical and structural description of the cosmic domain.

Keywords: Dahli cosmological model; membrane–string cosmology; dark matter depletion; cosmic vacuum structure; temporal-energy strings; cosmological constant; gamma-ray attenuation; Casimir effect

1 Introduction

The standard ΛCDM model combines General Relativity (GR) on large scales with a cold, collisionless dark-matter component and a cosmological constant Λ. This paradigm has been remarkably successful in fitting many cosmological observables, yet it suffers from several conceptual and empirical tensions:

- The cosmological-constant problem: the observed dark-energy density $\rho_\Lambda \sim 10^{-27}\,\mathrm{kg/m^3}$ is smaller than naive QFT estimates by about 10^{120}.
- Absence of dark-matter particles: decades of direct and indirect searches have produced null results.
- Conceptual extrapolation: GR+QFT are local theories tested inside galaxies and laboratories; their direct extrapolation to the entire cosmic domain is an assumption, not a measured fact.

In this work we develop the Dahli Cosmological Model (DCM), also called the Dahli internal cosmological model, which treats the dark sector as structural and geometric rather than particle-based. The key ingredients are:

(i) A *domain decomposition* of physical reality into three patterns P_1, P_2, P_3 with distinct ontological content.

(ii) A *membrane–string substrate* underlying both dark matter and dark energy.

(iii) A *structural order parameter* $\alpha(t)$ governing a phase transition from a closed-membrane (dark-matter) phase to an open-membrane plus temporal-string (cosmic-vacuum) phase.

Our objectives are:

- To formulate the structural and mechanical framework of DCM with explicit mathematics.
- To provide a logical critique of ΛCDM from the standpoint of domain separation.
- To derive clear, falsifiable predictions (gamma-ray attenuation, Casimir corrections).

Throughout, we deliberately avoid metaphorical language and instead use only explicit structural terminology: spatial membranes, temporal-energy strings, microscopic white holes, and domain indices.

2 Domain Structure of the Universe

2.1 Domain P_1: Local Einsteinian and Quantum Regime

Domain P_1 describes the interior of galaxies and the environment of terrestrial and laboratory experiments. It is modeled by:

- A 4D Lorentzian manifold $(M, g_{\mu\nu})$.
- A set of quantum fields $\{\Phi_i\}$ defined on M with Lagrangian density $\mathcal{L}_{\mathrm{SM}}$.

- Einstein equations with stress-energy $T_{\mu\nu}^{\text{vis}}$ from visible matter and radiation:

$$R_{\mu\nu} - \tfrac{1}{2} R g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}^{\text{vis}}. \tag{1}$$

Postulate 1 (Local validity). Within P_1, GR+QFT+SM are valid and empirically confirmed. No structural entities from P_2 or P_3 enter explicitly into $T_{\mu\nu}^{\text{vis}}$ at the level of local experiments.

This postulate ensures that all known successes of the standard model in particle physics, atomic physics, and local gravitational tests are preserved.

2.2 Domain P_2: Intergalactic Structural Vacuum

Domain P_2 represents the region between galaxies. Here, the following statements define the DCM ontology:

(a) There is no global QFT vacuum state and no global Hilbert space structure applicable to P_2.

(b) The fundamental building blocks are microscopic white holes (MWs).

We define the intergalactic structural vacuum as a set

$$\mathcal{V}_{\text{inter}} = \bigcup_{i \in \mathbb{Z}^3} \text{MW}_i, \tag{2}$$

where each MW_i is a localized, static configuration containing:

- Three mass membranes $\Sigma_i^{(1)}, \Sigma_i^{(2)}, \Sigma_i^{(3)}$ in superposition.
- Three contracted temporal-energy strings $\tau_i^{(1)}, \tau_i^{(2)}, \tau_i^{(3)}$ providing stability and tension.

These components define a composite object:

$$\text{MW}_i \equiv (\Sigma_i^{(1)}, \Sigma_i^{(2)}, \Sigma_i^{(3)}; \tau_i^{(1)}, \tau_i^{(2)}, \tau_i^{(3)}). \tag{3}$$

2.3 Domain P_3: Halo Region and Dark-Matter Phase

Domain P_3 describes galactic halos and outer regions where dark-matter effects are observed. The fundamental entities in P_3 are closed spatial membranes $\Sigma_j^{(c)}$.

We postulate a ternary closure operation

$$\Phi : (\Sigma_j^{(1)}, \Sigma_j^{(2)}, \Sigma_j^{(3)}) \mapsto \Sigma_j^{(c)}, \tag{4}$$

so that each closed membrane is the result of a $(3 \to 1)$ composition of contracted spatial branes.

The ensemble of closed membranes is

$$\Sigma_{\text{DM}} = \bigcup_{j \in J} \Sigma_j^{(c)}. \tag{5}$$

Each membrane $\Sigma_j^{(c)}$ is characterized by:

- Radius r_j,

- Surface tension σ_j,
- Intrinsic pressure

$$p_j = \frac{2\sigma_j}{r_j}, \tag{6}$$

- Effective mass density

$$\rho_j = \frac{p_j}{c^2}. \tag{7}$$

The macroscopic dark-matter density in P_3 is then

$$\rho_{\mathrm{DM}}(\mathbf{x}) = \sum_j \rho_j \, \delta^{(3)}(\mathbf{x} - \mathbf{x}_j), \tag{8}$$

coarse-grained over membrane ensembles.

3 Field Compression and Domain Transitions

3.1 Compression Tensor

The transition from the smooth field description in P_1 to the discrete membrane–string description in P_2 and P_3 is encoded by a compression tensor

$$\mathcal{C}_{\mu\nu} = \mathrm{diag}(+1, -\lambda_x, -\lambda_y, -\lambda_z), \tag{9}$$

with $0 < \lambda_{x,y,z} \ll 1$.

A local field $\phi_{\mathrm{P}_1}(x)$ maps to a structural configuration via

$$\phi_{\mathrm{P}_2,3}(x') = \mathcal{C}[\phi_{\mathrm{P}_1}](x'), \quad x'^{\mu} = \mathcal{C}^{\mu}{}_{\nu} x^{\nu}. \tag{10}$$

This map is not a dynamical equation of motion, but a structural relation that defines how continuous fields in P_1 correspond to discrete structural entities in P_2 and P_3.

3.2 Mechanics vs. Field Theory

The Dahli model is mechanical in the sense that:

- In P_1, dynamics are governed by field equations (GR and QFT).
- In P_2 and P_3, dynamics are governed by the mechanics of membranes and strings: tension, curvature, and discrete interactions.

This distinguishes local field theory from global cosmic mechanics.

4 Mathematical Nature of the Dahli Cosmological Model

The mathematical structure of the Dahli Cosmological Model is purely mechanical, structural, and organizational. It does not treat the cosmos as a global quantum field theory on a smooth spacetime manifold, but as a network of absolute, pure units of mass and energy: *mass membranes* and *energy strings*. In the cosmic domains P_2 and P_3, the only relevant variables are

the tension of temporal strings and the pressure of spatial membranes. The model therefore needs: (i) pure mass carriers in the form of closed or open membranes with well-defined surface tension and curvature; (ii) pure energy carriers in the form of contracted temporal strings with well-defined tension; and (iii) algebraic balance relations between string tension and membrane pressure. In particular, the cosmological sector of the model does *not* require a global Hilbert space, does not use wave functions or operators, does not rely on a dynamical spacetime metric or differential geometry, and does not invoke quantum or relativistic field equations outside the local Einsteinian domain P_1.

From this standpoint, the mathematics of DCM is a background algebra and a structural geometry, rather than a system of differential field equations. The fundamental objects are counted (numbers of membranes and strings), composed (via ternary $3 \to 1$ rules for fusion of membranes and strings), and constrained by simple algebraic relations (for example, between surface tension, radius, and effective mass, or between temporal tension and effective vacuum density). One may view this framework as the extraction and aggregation of the *mechanical cores* of quantum and relativistic dynamics: the hidden mechanical kernels that are implicit in GR and QFT (tension, pressure, curvature, energy densities) are isolated, abstracted, and reorganized into a single structural mechanics valid at the cosmological level. In this sense, the cosmic mathematics of the Dahli model is the sum of all such mechanical nuclei of standard dynamical equations, stripped of their local field-theoretic machinery and redeployed as a global algebraic and structural geometry for membranes and strings in the domains P_2 and P_3.

5 Structural Order Parameter and Phase States

5.1 Definition of $\alpha(t)$

Let N_{total} be the total number of structural membrane units (fundamental units that can appear in either closed or open configurations). Define:

$$\alpha(t) = \frac{N_{\text{open}}(t)}{N_{\text{total}}}, \tag{11}$$

so that

$$N_{\text{closed}}(t) = N_{\text{total}}[1 - \alpha(t)]. \tag{12}$$

Interpretation.

- $N_{\text{closed}}(t)$: membrane units in closed spatial configurations (dark-matter phase, P_3).
- $N_{\text{open}}(t)$: membrane units in open configurations combined with temporal strings (cosmic-vacuum phase, P_2).

5.2 Energy Densities

Assuming a homogeneous universe at large scales with scale factor $a(t)$, we write:

$$\rho_{\text{DM}}(t) = \rho^0_{\text{DM}}[1 - \alpha(t)]\, a^{-3}(t), \tag{13}$$

$$\rho_{\Lambda}(t) = \alpha(t)\frac{T_{\text{eff}}}{c^2}, \tag{14}$$

where:

- $\rho_{\rm DM}^0$ is a reference dark-matter density at some initial time.
- $T_{\rm eff}$ is the effective large-scale temporal-string tension.

Notice that $\rho_\Lambda(t)$ is constant in time if $T_{\rm eff}$ is constant and $\alpha(t)$ saturates, but in general it can have mild time dependence as the structural phase transition proceeds.

6 Dynamics of the Phase Transition

6.1 Logistic Evolution

We postulate that the fraction $\alpha(t)$ evolves according to a logistic equation:

$$\frac{d\alpha}{dt} = \kappa\,\alpha(t)\,[1-\alpha(t)], \tag{15}$$

where $\kappa > 0$ is a kinetic parameter.

The solution is

$$\alpha(t) = \frac{\alpha_0 e^{\kappa t}}{1-\alpha_0+\alpha_0 e^{\kappa t}}, \tag{16}$$

with $\alpha_0 = \alpha(0)$.

In terms of redshift z (with $1+z = a_0/a$ and H_0 the Hubble constant), for small κ/H_0 one can approximate

$$\alpha(z) \approx \frac{\alpha_0 (1+z)^{-\kappa/H_0}}{1-\alpha_0+\alpha_0(1+z)^{-\kappa/H_0}}. \tag{17}$$

6.2 Modified Continuity Equation

The continuity equation for dark matter acquires a source term:

$$\dot\rho_{\rm DM} + 3H\rho_{\rm DM} = -\Gamma_{\rm DM\to\Lambda}, \tag{18}$$

where

$$\Gamma_{\rm DM\to\Lambda} = \rho_{\rm DM}^0\,\dot\alpha(t)\,a^{-3}(t). \tag{19}$$

Since $\dot\alpha(t) > 0$, we have $\Gamma_{\rm DM\to\Lambda} > 0$, i.e. dark matter is depleted and converted into vacuum energy. The total energy density

$$\rho_{\rm tot} = \rho_{\rm DM} + \rho_\Lambda + \rho_{\rm vis} \tag{20}$$

still satisfies the usual Friedmann equations.

7 Planck Tension and Cosmological Constant

7.1 Fundamental Tension Scale

We take the fundamental tension as the Planck tension

$$T_{\rm P} = \frac{c^5}{G\ell_{\rm P}} \sim 10^{70}\,{\rm J/m}, \tag{21}$$

where $\ell_{\rm P} \sim 1.6 \times 10^{-35}\,\mathrm{m}$ is the Planck length.

The effective cosmic tension $T_{\rm eff}$ arises from a hierarchical damping over $N_{\rm hier}$ structural levels between $\ell_{\rm P}$ and the Hubble radius $R_H = c/H_0$:

$$T_{\rm eff} = T_{\rm P} \left(\frac{R_H}{\ell_{\rm P}} \right)^{-\lambda_{\rm struct}}, \tag{22}$$

with $0 < \lambda_{\rm struct} < 1$. Equivalently,

$$T_{\rm eff} = T_{\rm P} \prod_{k=1}^{N_{\rm hier}} \epsilon_k, \tag{23}$$

where $\epsilon_k < 1$ are damping factors at each level.

7.2 Effective Dark-Energy Density

The dark-energy density is

$$\rho_\Lambda(t) = \alpha(t) \frac{T_{\rm eff}}{c^2}. \tag{24}$$

If $\alpha(t)$ has already saturated to near unity in the late universe, then

$$\rho_\Lambda \approx \frac{T_{\rm eff}}{c^2}. \tag{25}$$

By choosing $\lambda_{\rm struct}$ (or equivalently the set $\{\epsilon_k\}$), one can reproduce the observed ρ_Λ without fine-tuning in the usual QFT sense: the small value is the result of a long hierarchical damping process from $T_{\rm P}$ to cosmological scales.

Interpretation.

- Λ is not vacuum energy of QFT fields.
- Λ is the macroscopic effect of cosmic temporal-string tension.
- The cosmological-constant problem is reframed: one must explain the structural damping, not cancel field-theoretic vacuum energies.

8 Dark Matter as Closed Spatial Membranes

8.1 Single Membrane Mechanics

Consider a closed, approximately spherical membrane of radius $r_{\rm M}$ and surface tension σ. The internal pressure is

$$p_{\rm M} = \frac{2\sigma}{r_{\rm M}}, \tag{26}$$

so the effective mass density is

$$\rho_{\rm M} = \frac{p_{\rm M}}{c^2} = \frac{2\sigma}{c^2 r_{\rm M}}. \tag{27}$$

The associated mass is

$$M_{\rm M} = 4\pi r_{\rm M}^2 \, \rho_{\rm M} = \frac{8\pi\sigma r_{\rm M}}{c^2}. \tag{28}$$

8.2 Halo Density Profile

Consider an ensemble of membranes with a number density $n(r_{\rm M}, R)$ depending on radius R from the galactic center and membrane size $r_{\rm M}$. The effective dark-matter density is

$$\rho_{\rm DM}(R) = \int n(r_{\rm M}, R)\, \rho_{\rm M}(r_{\rm M})\, dr_{\rm M}. \tag{29}$$

To obtain a flat rotation curve $v_c(R) \approx \text{const}$, we require

$$\rho_{\rm DM}(R) \propto \frac{1}{R^2}. \tag{30}$$

This can be realized with a scaling

$$n(r_{\rm M}, R) \propto R^{-2}\, f(r_{\rm M}/R_{\rm max}), \tag{31}$$

for some cutoff function f. Then

$$M_{\rm enc}(R) = \int_0^R 4\pi R'^2 \rho_{\rm DM}(R')\, dR' \propto R, \tag{32}$$

and

$$v_c(R) = \sqrt{\frac{GM_{\rm enc}(R)}{R}} = \text{const}. \tag{33}$$

Thus, dark-matter phenomenology (flat rotation curves) emerges from membrane pressure, not from a collisionless particle fluid.

9 Open Membranes and Temporal Strings: Cosmic Vacuum

9.1 Microscopic White Holes as Structural Units

Each MW in P_2 is an open membrane complex with three mass membranes and three temporal strings. The total energy associated with one MW is

$$\mathcal{E}_{\rm MW} = \sum_{i=1}^{3} T_{\rm eff} \ell_i, \tag{34}$$

where ℓ_i are the effective lengths of the contracted temporal strings.

A large ensemble of MWs per unit volume generates an average energy density

$$\rho_{\rm vac} = n_{\rm MW}\, \frac{\mathcal{E}_{\rm MW}}{c^2}, \tag{35}$$

which matches ρ_Λ if $n_{\rm MW}$ and $T_{\rm eff}$ are chosen consistently.

9.2 Equation of State

The vacuum pressure arises from the tension of temporal strings. On large scales, the equation of state has the form

$$p_\Lambda = -\rho_\Lambda c^2, \tag{36}$$

equivalent to $w = -1$. However, in DCM this relation is structural (due to tension), not a consequence of QFT vacuum.

10 Gamma-Ray Attenuation in P_2

10.1 Standard Attenuation

In ΛCDM, high-energy gamma-rays from distant sources are attenuated by pair production on background photon fields such as the extragalactic background light (EBL) and the cosmic microwave background (CMB). The flux is

$$F_{\Lambda\mathrm{CDM}}(E,z) = \frac{F_{\mathrm{em}}(E')}{4\pi D_L^2(z)} \exp[-\tau_{\mathrm{pair}}(E,z)], \tag{37}$$

where $E' = E(1+z)$ is the emitted energy, $D_L(z)$ is the luminosity distance, and τ_{pair} is the optical depth.

10.2 Additional Structural Attenuation

In DCM, photons entering P_2 become effective string excitations propagating through the MW network. We model an additional attenuation factor

$$\Gamma(D_L, E, \gamma_N) = \exp\big[-\gamma_N f(D_L, E)\big], \tag{38}$$

with

$$f(D_L, E) = \left(\frac{D_L(z)}{\ell_g}\right)^{\alpha_d} \left(\frac{E}{E_0}\right)^{\beta_d}, \tag{39}$$

where:

- ℓ_g is the characteristic spacing between MWs,
- γ_N is a dimensionless attenuation strength,
- $\alpha_d, \beta_d > 0$ are structural exponents,
- E_0 is a reference energy.

The observed flux is

$$F_{\mathrm{obs}}(E,z) = F_{\Lambda\mathrm{CDM}}(E,z)\,\Gamma(D_L, E, \gamma_N), \tag{40}$$

so that

$$R(E,z) \equiv \frac{F_{\mathrm{obs}}}{F_{\Lambda\mathrm{CDM}}} = \exp\big[-\gamma_N f(D_L, E)\big]. \tag{41}$$

Including the structural evolution via $\alpha(z)$, we refine

$$\ln R(E,z) = -\gamma_N \left(\frac{D_L(z)}{\ell_g}\right)^{\alpha_d} \left(\frac{E}{E_0}\right)^{\beta_d} \alpha(z)^{\alpha_d/3}. \tag{42}$$

Key prediction. For fixed E and for $\alpha(z)$ increasing with cosmic time (decreasing with z),

$$\frac{d}{dz}|\ln R(E,z)| < 0. \tag{43}$$

That is, the additional attenuation is *stronger* for nearby sources (low z) than for more distant ones at the same energy. This trend is opposite to most conventional attenuation mechanisms, and thus provides a clean test of dark-matter depletion and the structural vacuum.

11 Casimir Effect Modifications

11.1 Standard Casimir Force

For two perfectly conducting parallel plates of area A separated by distance d in standard QED,

$$F_{\mathrm{QED}}(d) = -\frac{\pi^2 \hbar c}{240 d^4} A. \tag{44}$$

11.2 Structural Correction in DCM

In a structural vacuum composed of MWs and temporal strings, the mode structure of the electromagnetic field is slightly modified due to the underlying length scale ℓ_g and the membrane–string dynamics. We parameterize this as

$$F_{\mathrm{total}}(d) = F_{\mathrm{QED}}(d)\,[1 + \delta_{\mathrm{struct}}(d)], \tag{45}$$

with

$$\delta_{\mathrm{struct}}(d) \sim \kappa_{\mathrm{C}} \left(\frac{d}{\ell_g}\right)^n, \quad \kappa_{\mathrm{C}} \ll 1, \quad n > 0. \tag{46}$$

For d in the range $100\,\mathrm{nm} \lesssim d \lesssim 1\,\mu\mathrm{m}$, high-precision Casimir measurements can constrain ℓ_g and κ_{C}, independently probing the same structural scale entering gamma-ray attenuation.

12 Logical Critique of ΛCDM

12.1 Category Errors

From the DCM perspective, several aspects of ΛCDM involve mixing concepts from different domains:

(1) Vacuum energy vs. cosmic vacuum. QFT vacuum energy is defined in P_1 as an expectation value in a Hilbert space. The cosmic vacuum in P_2 is a structural membrane–string network. Comparing these directly and demanding equality constitutes a category error.

(2) Particle dark matter vs. membrane pressure. Interpreting the gravitational effects in P_3 as arising from a particle fluid is not mandated by GR; an effective stress-energy tensor from membrane pressure is equally valid, and more natural within DCM.

(3) Global QFT. Extending local QFT concepts (virtual particles, global vacuum) to the entire universe, including P_2, is not experimentally justified and leads to paradoxes.

12.2 Local vs. Cosmological Validity

All direct experimental tests of QFT and SM are confined to P_1. Cosmic-scale phenomena involve P_2 and P_3, where structural mechanics replaces field-theoretic descriptions. DCM thus confines:

- GR+QFT+SM to P_1 as effective local theories.
- Membrane–string mechanics to P_2 and P_3 as the correct cosmological description.

13 Comparison with Other Approaches

13.1 Particle Dark Matter

DCM reproduces several large-scale phenomena usually attributed to cold dark matter (CDM), but with crucial differences:

- No new particle species is required.
- Null results in direct-detection experiments become natural: no particles exist to scatter.
- Halo profiles arise from structural membrane distributions, not from N-body particle simulations.

13.2 Modified Gravity

In DCM, the Einstein field equations are not modified at the fundamental level. Instead, the source term $T_{\mu\nu}$ is structurally enriched by membrane pressure and temporal tension. Gravity remains GR; the matter content is reinterpreted.

13.3 Emergent and Entropic Gravity

DCM shares with emergent-gravity approaches the idea that dark phenomena may arise from deeper microstructure. However:

- DCM provides explicit mechanical entities (membranes, strings, MWs) and a concrete hierarchy from T_{P} to T_{eff}.
- Predictions (gamma-ray attenuation, Casimir corrections) are expressed in terms of specific structural parameters ($\ell_g, \gamma_N, \kappa, n$), improving falsifiability.

14 Implications and Outlook

14.1 For Cosmology

The Dahli cosmological model offers:

- A unified structural origin for both dark matter and dark energy.
- A mechanism for dark-matter depletion over cosmic time.
- A reinterpretation of Λ as cosmic temporal tension.

14.2 For Fundamental Physics

- QFT and SM are demoted from universal descriptions to domain-specific theories valid in P_1.
- Planck tension T_{P} is highlighted as the fundamental scale, with G and Λ emerging from structural hierarchies.

14.3 Predictions Summary

DCM makes the following qualitative and quantitative predictions:

1. **No dark-matter particles**: continued null results in direct-detection and collider searches.
2. **Dark-matter depletion**: effective $\rho_{\mathrm{DM}}(t)$ decreases faster than $a^{-3}(t)$, due to $\alpha(t)$ increasing.
3. **Cosmic-vacuum growth**: $\rho_{\Lambda}(t)$ mildly increases with $\alpha(t)$ until saturation.
4. **Gamma-ray signatures**: extra attenuation factor with $d|\ln R|/dz < 0$ at fixed energy.
5. **Casimir deviations**: small scale-dependent corrections at sub-micrometer separations, correlated with ℓ_g.

15 Conclusion

We have constructed a structural, mechanical cosmological model in which:

- The universe is partitioned into three domains P_1, P_2, P_3 with distinct ontologies.
- Dark matter and dark energy are two phases of a single membrane–string substrate.
- A structural order parameter $\alpha(t)$ controls a phase transition from closed spatial membranes to open membrane plus temporal-string configurations, resulting in dark-matter depletion into cosmic vacuum.
- The cosmological constant problem is reframed by interpreting Λ as effective temporal tension T_{eff} obtained from Planck tension through hierarchical damping.
- Clear, falsifiable predictions are derived for high-energy gamma-ray attenuation and Casimir-force corrections.

This model confines GR+QFT+SM to their proper local domain and replaces speculative particle dark matter and bare vacuum energy by a concrete mechanical and structural framework. If the predicted gamma-ray and Casimir signatures are observed, DCM would represent a genuine paradigm shift in our understanding of the dark sector and the global structure of the universe.

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